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AGRICULTURAL MEMORANDUM NO. 1059

# DROUGHT FACTOR FOR AN IMPROVED ADAS AGRICULTURAL LAND CLASSIFICATION

## INTRODUCTION

The climatic contribution to drought in growing crops is through the increasing evapotranspiration rates as the summer approaches coupled with occasions of little or no rain leading to increasing Soil Moisture Deficit (SMD) followed by a reduced crop transpiration and hence reduced growth. The reduction in crop transpiration below the full potential rate is a simple measure of agricultural drought, after Tabony (1977), viz:-

$$D = PE - AE \quad \ldots\ldots\ldots\

Following the analytical approach outlined in Annexe A, the model equation of the actual SMD curve, shown graphically as the dot-dash line in Fig.1, takes the form

$$SMD = PSMD - AWC + 0.6\ AWC \exp(-B\ (PSMD - 0.4\ AWC)) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where $B = 1/0.6\ AWC$.

Using this value of B in equation 3 and substituting SMD given by this equation into equation 2 gives the following agricultural drought index D.

$$D = PSMD - AWC + 0.6\ AWC \exp(-(0.6\ AWC)^{-1}(PSMD - 0.4\ AWC)) \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

This model relates D to accumulated PSMD and AWC in a non-linear, ie interactive, way. It is instructive to remember that there exists an infinite number of SMD curves, see Fig. 2, each corresponding to a specified soil AWC.

Generally the PSMD increases as the summer progresses and a maximum PSMD is reached sometime between June and October depending upon the crop, and the weather in a particular year. For Agricultural Land Classification (ALC) purposes, ie for detailed mapping of droughtiness over the country, the maximum PSMD may be used, or more precisely the median value of 20 years of annual maximum PSMD (Max PSMD), in place of PSMD in equation 4. The ADAS ALC is intended to provide an overall assessment of agricultural performance therefore the Max PSMD is calculated for grass which acts like a reference crop because it assumes a large leaf area index all summer long.

Comparison with Soil Survey of England and Wales Scheme

Equation 4 offers a soundly based system of combining soil and climate factors for determining an agricultural drought index in ALC. Also it could be used for land utilisation studies with specific end of month PSMD relevant to different crops, after Thomasson (1979). Thomasson (1979) and Keers (1984) used a drought factor ($D_T$) given in the notation of this paper by

$$D_T = PE - (RAIN + AWC)$$
$$= PSMD - AWC \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

which is the difference between the potential moisture losses and actual moisture gains. This overcomes the difficulty of modelling the actual SMD which is a requirement if soil and weather factors are to be interactive as they undoubtedly are in practice. The shaded area in Fig. 1 illustrates the difference between using equations 4 and 5 for deriving a drought index.

Having derived a drought index it remains to determine thresholds for ALC purposes and this requires many data on actual droughtiness for a wide selection of soils in different areas of the country. Alternatively the droughtiness scheme of the Soil Survey of England and Wales as portrayed in Fig. 3(a) may be applied to the drought index described in this paper to produce the thresholds given in Fig 3(b). The max PSMD values used in Figs. 3(a) and (b) are those used by the Soil Survey and they are different from max PSMD values derived from the Met Office MORECS program.

An alternative to modelled Max PSMD

The difficulty of uniquely determining max PSMD for ADAS ALC work can be overcome by reverting to the basic, ie measured, meteorological parameters, temperature, sunshine, rainfall, wind and humidity. A physical - empirical model relating max PSMD to average summer rainfall ($R_S$) and summer (April-September) accumulated temperature ($T_S$) is described by the following equation for values of R less than 400 mm, ie Average Annual Rainfall less than 800 mm approximately, after Keers (1984).

$$\text{Max PSMD} = 0.167T_S - 0.407R_S - 97 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

For England and Wales sunshine is not a useful, independent, term in equation 6 because it is highly correlated with temperature, especially during the months June, July and August which are potentially the most damaging months for agricultural drought. It follows from Equation 6 that to a good approximation Max PSMD is proportional to T -2.5R and hence may be used in place of Max PSMD in the drought category diagram as shown in Fig. 4.

Wind speed is a significant variable in the general evaporative theory, however, the variation of mean summer wind speed over the country chiefly varies with altitude and distance fom the west coast which is very similar to the rainfall distribtuion. Therefore, the inclusion of the mean wind factor as

an independent term in Equation 6 is not significant (less than 3 per cent of the variability of Max PSMD accounted for). Some allowance for the extreme effects of exposure to wind at the coast, especially south and west coasts, must be allowed for separate from the drought considerations.

## Conclusions

A revised model for agricultural drought described in this paper has two advantages over Thomassons's (1979) scheme. First the model derives from first principles applied to soil moisture extraction ideas using evaporative losses and rainfall replenishments coupled with the soil AWC, and thereby accounts for any non-linear interactions between soil and climate factors.

Second the use of summer temperature and summer rainfall in place of max PSMD overcomes the practical difficulties resulting from widely different max PSMD values being computed depending on the evaporative model and the precise data inputs.

## Acknowledgment

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Key Words Soil Moisture, drought, evaporation, land classification.

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References:

Tabony R.C. (1977) - Drought Classifications and a study of drought at Kew, Met Mag. 206, pp 1-1 0.

Thompson N, Barrie I.A., Ayles M (1981) - The Met Office Rainfall and Evaporation Calculation System: MORECS. Met. O. Hyd. Mem No.45.

Thomasson A.J. (1979) - Soil Droughtiness in Soil Survey Applications. Tech Mono No. 13. Harpenden: Soil Survey of England and Wales.

Keers (1984) - A Droughtiness Factor for Agricultural Land Classificaton. Met 08a Agricultural Memo No 987.

Annex A to Ag. Mem No 1059

Analytical derivation of an expression for Soil moisture Deficit (SMD) with PSMD and AWC as independent parameters

In general form we can write:

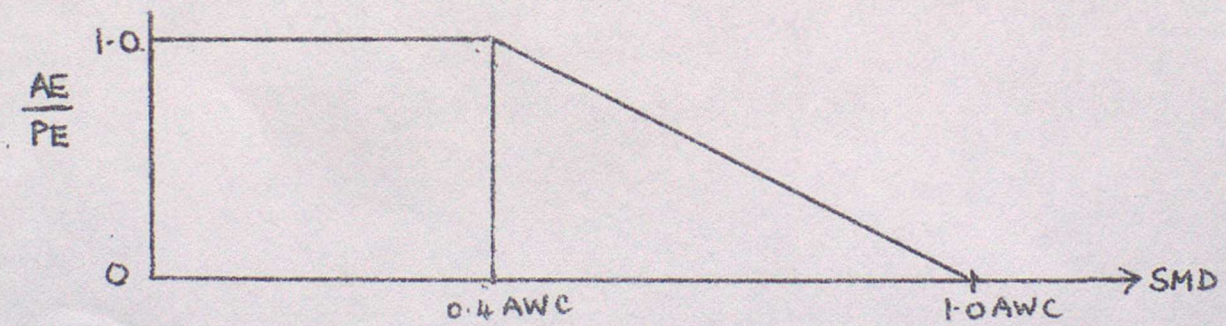
$$SMD = SMD_o + AE - R \quad \ldots\ldots (1A)$$

Where $SMD_o$ and SMD are the soil moisture deficits at some initial time and at a short time later, AE is the actual evaporation/transpiration and R the rainfall during this time interval.

Now assume this rainfall is evaporated/transpired at potential rate regardless of SMD, then

$$SMD = SMD_o + AE\ \frac{(PE - R)}{PE} + PE.\ \frac{R}{PE} - R \quad \ldots\ldots (2A)$$

$$= SMD_o + AE\ \frac{(PE - R)}{PE} \quad \ldots\ldots (3A)$$




Now make the simplest possible assumption that $\frac{AE}{PE}$ declines linearly from 1.0 at $SMD = SMD_o = 0.4$ AWC, to 0.0 at SMD = AWC, then for $SMD \geq 0.4$ AWC

$$AE = PE\ \frac{(AWC - SMD)}{AWC - SMD_o} \quad \ldots\ldots (4A)$$

Substituting Equation 4A into 3A gives,

$$SMD = SMD_o + \frac{(AWC - SMD)}{AWC - SMD_o}\ (PE - R) \quad \ldots\ldots (5A)$$

now with $S \equiv SMD$

$$dS = \frac{(AWC - S)}{AWC - S_o}\ (PE - R)\ dt \quad \ldots\ldots (6A)$$

and putting $S_o = 0.4$ AWC and integrating equation 6A w.r.t. time

$$-\ln (AWC - S) = \frac{1}{0.6\ AWC} (PE - R)\ t + \text{constant} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7A)$$

$$= \frac{1}{0.6\ AWC} (PSMD + \text{constant}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8A)$$

The constant is evaluated by considering the conditions when $S = S_o = 0.4\ AWC = PSMD_o$, because AE = PE up to S = 0.4 AWC, and substituting in Equation 8A:-

$$\text{constant} = -0.6\ AWC.\ \ln (0.6\ AWC) - 0.4\ AWC \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9A)$$

and substituting this general form of the constant of integration back into Equation 8A gives,

$$SMD = AWC - \exp \left\{ - \frac{1}{0.6\ AWC} (PSMD - 0.6\ AWC \ln (0.6\ AWC) - 0.4\ AWC) \right\} 10\ A$$

$$\text{i.e.}\quad SMD = AWC - 0.6\ AWC \exp \left\{ - \frac{1}{0.6\ AWC} (PSMD - 0.4\ AWC) \right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots 11A$$

Equation 11A is the required analytical expression for soil Moisture Deficit with the assumptions (i) that AE = PE until the SMD reaches 40 per cent of the soil Available Water Content and then AE/PE linearly reduces to zero as SMD increases to the AWC value, and (ii) that any rainfall after SMD begins to accumulate above zero is evaporated/transpired at the potential rate.

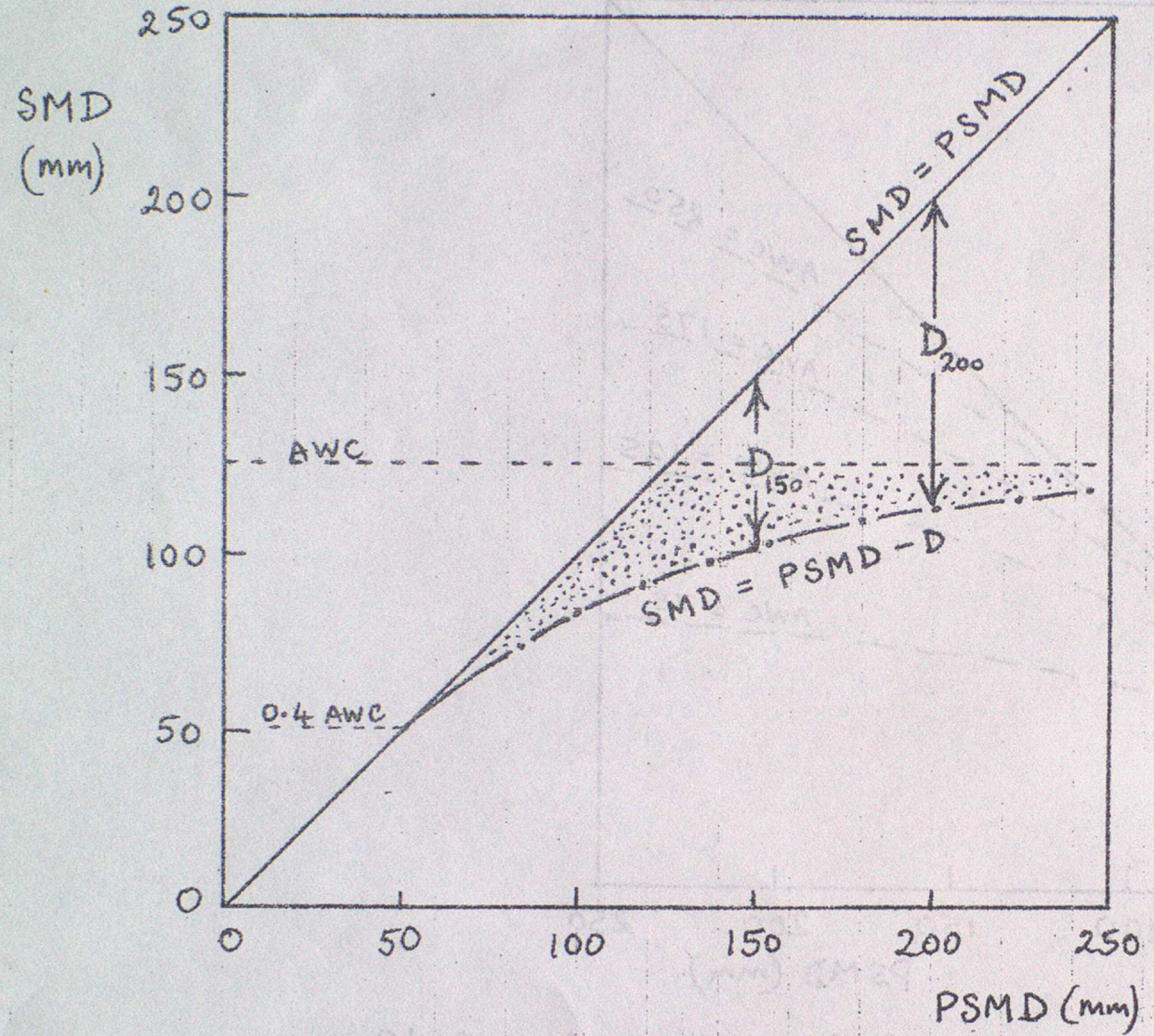



FIG 1. Graphical representation of a simple agriculture drought factor D = PSMD − SMD (—·—·—) as a function of PSMD and soil AWC. D approximates to PSMD − AWC for large value of PSMD and D approaches 0 as PSMD reduces to 0·4 AWC.

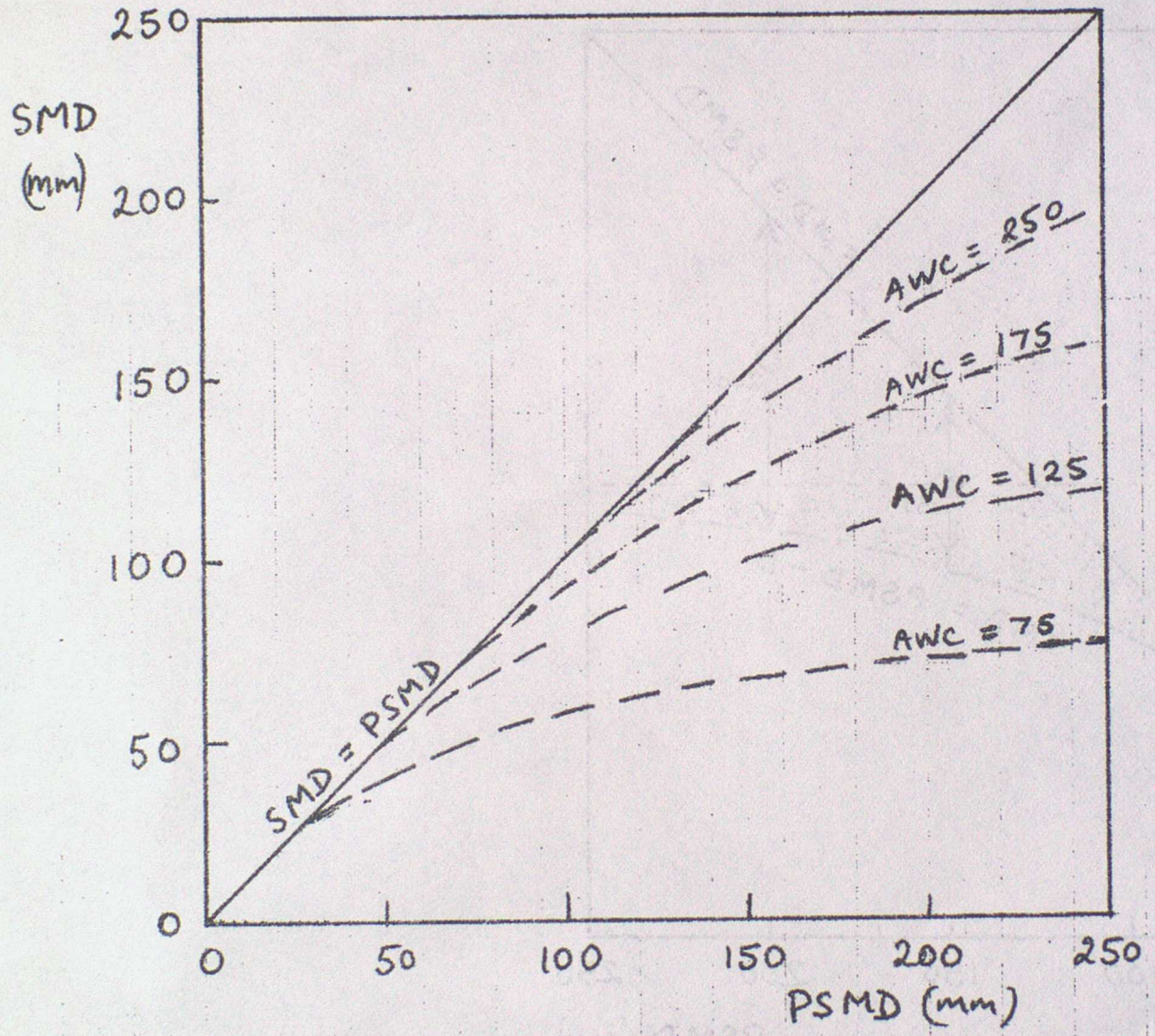



FIG 2. SMD MODEL SHOWING THE DEPENDENCE ON SOIL AWC AND SPECIFIED PSMD.

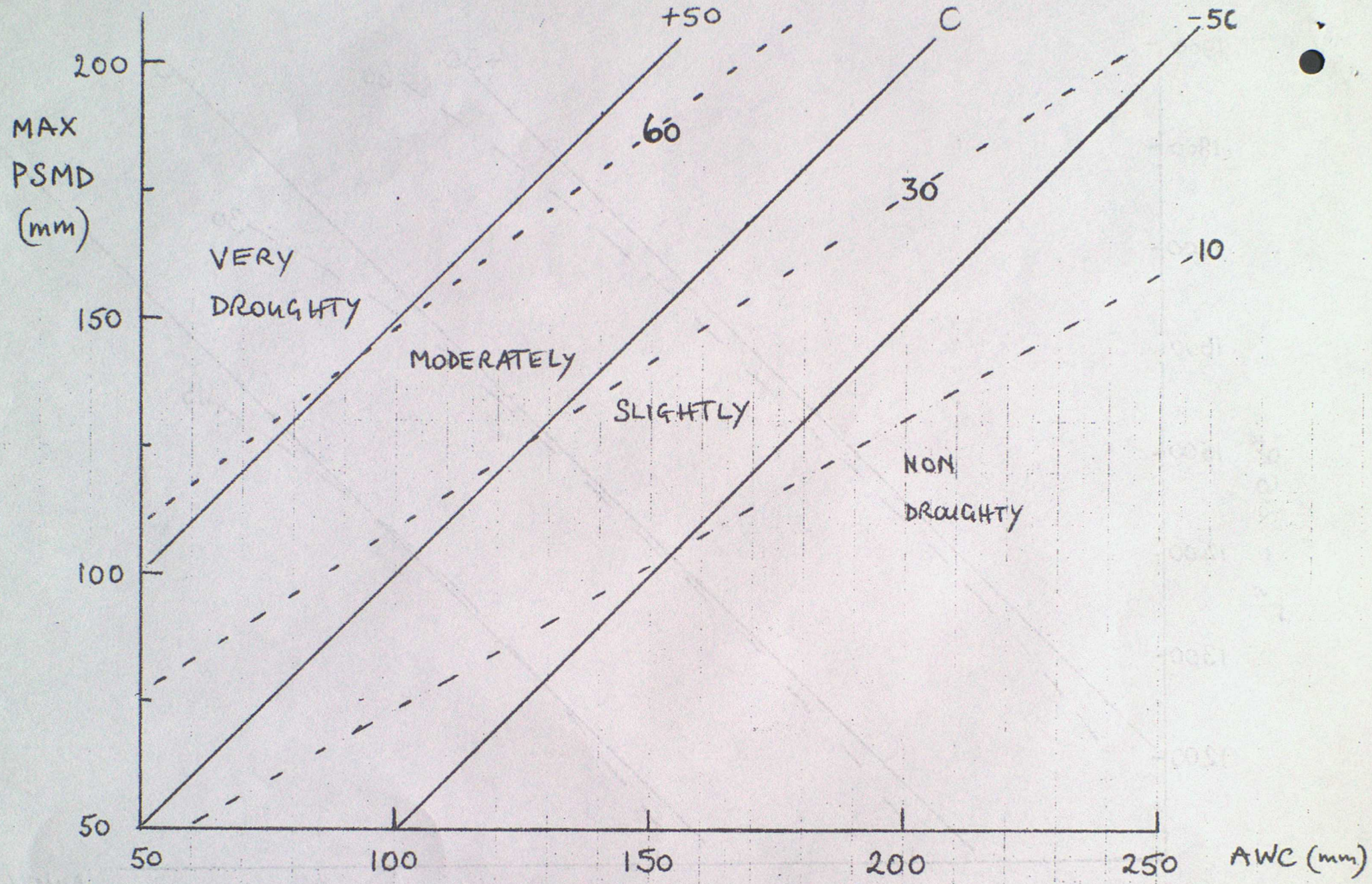



FIG 3. (a) DROUGHT INDEX (MAX PSMD – AWC) after Soil Survey E+W. ——
(b) DROUGHT INDEX D (EQUATION 4) in this paper – – – – –

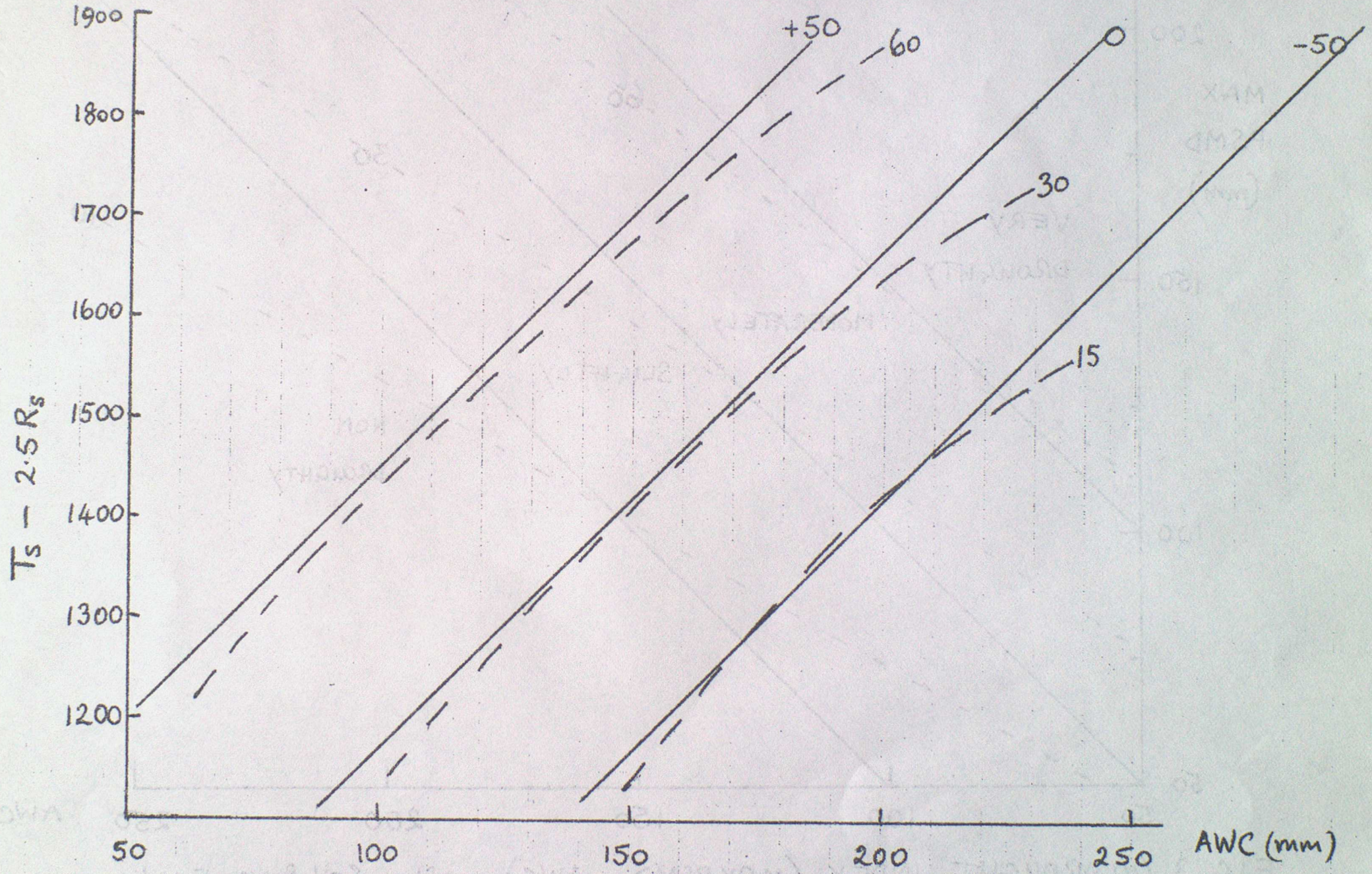



FIG 4 DROUGHT CATEGORIES after Soil Survey E+W. ——————

DROUGHT INDEX D after EQUATIONS 4 and 6 in this paper — — —